## 621.1 WOO 4<sup>th</sup> ed.

## CONTENTS

		Page
1.	BOILERS	1
	1.1 The Boiler	1
	1.2 Fire-Tube Boilers	2
	1.3 Water-Tube Boilers	9
	1.4 Steam Separators and Superheaters	21
	1.5 Heat-Recovery Equipment	26
	1.6 Furnace construction	32
	1.7 Industrial and Utility Boilers	39
	Questions and Problems	57
2.	DESIGN AND CONSTRUCTION OF BOILERS	61
	2.1 Materials Used in Boiler Construction	61
	2.2 Stresses in Tubes, Boiler Shells, and Drums	65
	2.3 Drum and Shell Construction	71
	2.4 Riveted Joints	73
	2.5 Welded Construction	76
	2.6 Braces and Stays	79
	2.7 Manholes, Handholes, and Fittings	81
	2.8 Boiler Assembly	82
	2.9 Heating Surface and Capacity	85
	2.10Boiler-Capacity Calculation	89
	Questions and Problems	93
3.	COMBUSTION OF FUELS	96
	3.1 The Combustion Process	96
	3.2 The Theory of Combustion	100
	3.3 The Air Supply	111
	3.4 Coal	117
	3.5 Fuel Oil	126
	3.6 Gas	130
	3.7 By-Product Fuels	132
	3.8 Control of the Combustion Process	133
	Questions and Problems	140
4.	SETTINGS, COMBUSTION EQUIPMENT, AND HEATING SURFACES	142
	4.1 Boiler Settings	142
	4.2 Hand Firing	145
	4.3 Chain-and Traveling-Grate Stokers	147
	4.4 Underfeed Stoker	152
	4.5 Spreader Stoker	162
	4.6 Pulverized Fuel	176
	4.7 Fluidized-Bed Combustion	194
	4.8 Fuel Oil	195
	4.9 Gas	206
	4.10 Automatic operation of Boilers	210
	4.11Chimneys	214
	4.12Mechanical Draft	216
	4.13Steam and Air Jets	222
	4.14Air Pollution Control	223
	Questions and Problems	230

5.	BOILER ACCESSORIES	232
	5.1 Water Columns	232
	5.2 Fusible Plugs	237
	5.3 Steam Gauges	239
	5.4 Feedwater Regulators	241
	5.5 Safety Valves	246
	5.6 Blowdown Apparatus	254
	5.7 Nonreture Valves	259
	5.8 Steam Headers	262
	5.9 Soot Blowers	263
	5.10 Valves	269
	5.11Instruments and Automatic Combustion Control	275
	Questions and Problems	280
6.	OPERATION AND MAINTENANCE OF STEAM BOILERS	283
••	6.1 Putting Boilers in Operation	283
	6.2 Normal Operation	286
	6.3 Operating in an Emergency	299
	6.4 Idle Boilers	303
	6.5 Maintenance-Causes and Reduction	305
	6.6 Boilers Internal Inspection	312
	6.7 Making Repairs	314
	Questions and Problems	322
7.	PUMPS	324
/.		324 324
	7.1 Pumps 7.2 Injectors	324
	7.2 Injectors 7.3 Duplex Pumps	328
	7.3 Duplex Pumps 7.4 Simplex Pumps	338
	7.4 Simplex Fumps 7.5 Power Pumps	339
	7.6 Vacuum Pumps	340
	7.7 Rotary Pumps	343
	7.8 Centrifugal Pumps	346
	7.9 Pump Installation and Operation	360
	7.10Pump Testing and Calculations	364
	7.11Pump Maintenance	370
	Questions and Problems	376
	Questions and Problems	370
8.	RECIPROCATING STEAM ENGINES	380
	8.1 Pistons and Cylinders	381
	8.2 Pistons Rods, Crossheads, and Connecting Rods	384
	8.3 Crank, Flywheel, and Valve Mechanism	387
	8.4 Frames and Foundations	390
	8.5 Governers	390
	8.6 Engine Speed	396
	8.7 Compound Engines	398
	8.8 Condensing Engines	400
	8.9 Uniflow Engines Questions and Problems	401 402
9.	VALVE-OPERATING MECHANISM	<b>405</b> 405
	9.1 Cycle of Events 9.2 Function of Valve	403
	9.3 The Slide Valve	415
	9.4 Piston Valves	413
	9.4 Piston valves 9.5 Corliss Valves	417
	9.6 Poppet Valves	425
	9.7 The Uniflow Engine	423
	Questions and Problems	433
	Zaconomo una i rociomo	733

10.2Lubrication of Steam Engines       437         10.3Operating a Steam Engine       444         10.4Maintenance of Steam Engines       445         10.5Economy of Steam Engines       451         10.6Steam-Engine Indicators       452         10.7Engine Rating and Efficiency Questions and Problems       463         11. STEAM TURBINES AND AUXILIARIES       466         11.1Turbines: General       466         11.2Condensers       497         11.3Spray Ponds and Cooling Towers       504         11.4Condenser Auxiliaries       511         Questions and Problems       515         12. OPERATING AND MAINTAINING TURBINES AND AUXILIARIES       517         12.1Turbines       517         12.2Condensers       536         12.3Cooling, Towers and Spray Ponds       536         12.4Auxiliaries       541         Questions and Problems       545         13. AUXILIARY STEAM-PLANT EQUIPMENT       547         13. AUXILIARY STEAM-PLANT EQUIPMENT       547         13. AEvaporators       556         13.5Boiler Blowdown       562         13.6Piping System       564         13.7Steam Traps       573         13.8Pipeline Separators and Strainers       578 <t< th=""><th>10.</th><th>OPERATION AND MAINTENANCE OF STEAM ENGINES</th><th>435</th></t<>	10.	OPERATION AND MAINTENANCE OF STEAM ENGINES	435
10.3 Operating a Steam Engine       444         10.4 Maintenance of Steam Engines       447         10.5 Economy of Steam Engines       451         10.6 Steam-Engine Indicators       453         10.7 Engine Rating and Efficiency Questions and Problems       463         11. STEAM TURBINES AND AUXILIARIES       466         11.1 Turbines: General       466         11.2 Condensers       497         11.3 Spray Ponds and Cooling Towers       504         11.4 Condenser Auxiliaries       511         Questions and Problems       515         12. OPERATING AND MAINTAINING TURBINES AND AUXILIARIES       517         12.1 Turbines       517         12.2 Condensers       530         12.3 Cooling, Towers and Spray Ponds       536         12.4 Auxiliaries       541         Questions and Problems       545         13. AUXILIARY STEAM-PLANT EQUIPMENT       547         13. AUXILIARY STEAM-PLANT EQUIPMENT       547         13. AEvaporators       556         13. Alexaporators       560         13. Alexaporators       560         13. Alexaporators       560         13. Spieler Blowdown       562         13. Spipeline Separators and Strainers       578			435
10.4 Maintenance of Steam Engines 10.5 Economy of Steam Engines 10.6 Steam-Engine Indicators 10.7 Engine Rating and Efficiency Questions and Problems 453 10.7 Engine Rating and Efficiency Questions and Problems 463 11. STEAM TURBINES AND AUXILIARIES 11.1 Turbines: General 466 11.2 Condensers 497 11.3 Spray Ponds and Cooling Towers 11.4 Condenser Auxiliaries Questions and Problems 512. OPERATING AND MAINTAINING TURBINES AND AUXILIARIES 12.1 Turbines 12.2 Condensers 12.3 Cooling, Towers and Spray Ponds 12.4 Auxiliaries Questions and Problems 513 12.4 Auxiliaries Questions and Problems 545 13. AUXILIARY STEAM-PLANT EQUIPMENT 13.1 Open Feedwater Heaters 13.2 Closed Feedwater Heaters 13.2 Closed Feedwater Heaters 13.3 Ion-Exchange Water Conditioners 13.4 Evaporators 13.5 Boiler Blowdown 562 13.5 Boiler Blowdown 563 13.6 Piping System 13.7 Steam Traps 13.8 Pipeline Separators and Strainers 13.9 Lubricants and Lubricating Devices Questions and Problems 596			437
10.5 Economy of Steam Engines       451         10.6 Steam-Engine Indicators       453         10.7 Engine Rating and Efficiency       458         Questions and Problems       463         11. STEAM TURBINES AND AUXILIARIES       466         11.1 Turbines : General       466         11.2 Condensers       497         11.3 Spray Ponds and Cooling Towers       504         11.4 Condenser Auxiliaries       511         Questions and Problems       515         12. OPERATING AND MAINTAINING TURBINES AND AUXILIARIES       517         12.1 Turbines       517         12.2 Condensers       530         12.2 Cooling, Towers and Spray Ponds       536         12.3 Cooling, Towers and Spray Ponds       536         12.4 Auxiliaries       547         Questions and Problems       545         13. AUXILIARY STEAM-PLANT EQUIPMENT       547         13.1 Open Feedwater Heaters       547         13.2 Closed Feedwater Heaters       557         13.4 Evaporators       556         13.5 Boiler Blowdown       562         13.6 Piping System       564         13.7 Steam Traps       573         13.8 Pipeline Separators and Strainers       578         13.9 Lu			444
10.6Steam-Engine Indicators       453         10.7Engine Rating and Efficiency Questions and Problems       458         Questions and Problems       463         11. STEAM TURBINES AND AUXILIARIES       466         11.1Turbines: General       466         11.2Condensers       497         11.3Spray Ponds and Cooling Towers       504         11.4Condenser Auxiliaries       511         Questions and Problems       515         12. OPERATING AND MAINTAINING TURBINES AND AUXILIARIES       517         12.1Turbines       517         12.2Condensers       536         12.3Cooling, Towers and Spray Ponds       536         12.4Auxiliaries       541         Questions and Problems       545         13. AUXILIARY STEAM-PLANT EQUIPMENT       547         13.1Open Feedwater Heaters       547         13.2Closed Feedwater Heaters       557         13.4Evaporators       556         13.5Boiler Blowdown       562         13.6Piping System       564         13.7Steam Traps       573         13.8Pipeline Separators and Strainers       578         13.9Lubricants and Lubricating Devices       581         Questions and Problems       596		10.4Maintenance of Steam Engines	447
10.7Engine Rating and Efficiency Questions and Problems       458         Questions and Problems       463         11. STEAM TURBINES AND AUXILIARIES       466         11.1Turbines: General       466         11.2Condensers       497         11.3Spray Ponds and Cooling Towers       504         11.4Condenser Auxiliaries       511         Questions and Problems       512         12. OPERATING AND MAINTAINING TURBINES AND AUXILIARIES       517         12.1Turbines       517         12.2Condensers       536         12.4Auxiliaries       536         12.4Auxiliaries       541         Questions and Problems       545         13. AUXILIARY STEAM-PLANT EQUIPMENT       547         13.1Open Feedwater Heaters       547         13.2Closed Feedwater Heaters       557         13.4Evaporators       550         13.4Evaporators       560         13.5Boiler Blowdown       562         13.7Steam Traps       573         13.8Pipling System       564         13.9Lubricants and Lubricating Devices       581         Questions and Problems       590			451
Questions and Problems       463         11. STEAM TURBINES AND AUXILIARIES       466         11.1Turbines: General       466         11.2Condensers       497         11.3Spray Ponds and Cooling Towers       504         11.4Condenser Auxiliaries       511         Questions and Problems       515         12. OPERATING AND MAINTAINING TURBINES AND AUXILIARIES       517         12.1Turbines       517         12.2Condensers       536         12.2Aouiliaries       536         Questions and Problems       549         13. AUXILIARY STEAM-PLANT EQUIPMENT       547         13.1Open Feedwater Heaters       547         13.2Closed Feedwater Heaters       557         13.3Ion-Exchange Water Conditioners       550         13.4Evaporators       560         13.5Boiler Blowdown       562         13.7Steam Traps       573         13.8Pipling System       564         13.7Steam Traps       573         13.9Lubricants and Lubricating Devices       581         Questions and Problems       590		e e e e e e e e e e e e e e e e e e e	453
11. STEAM TURBINES AND AUXILIARIES       466         11.1Turbines : General       466         11.2Condensers       497         11.3Spray Ponds and Cooling Towers       504         11.4Condenser Auxiliaries       511         Questions and Problems       515         12. OPERATING AND MAINTAINING TURBINES AND AUXILIARIES       517         12.1Turbines       517         12.2Condensers       536         12.3Cooling, Towers and Spray Ponds       536         12.4Auxiliaries       541         Questions and Problems       542         13. AUXILIARY STEAM-PLANT EQUIPMENT       547         13.1Open Feedwater Heaters       547         13.2Closed Feedwater Heaters       554         13.3Ion-Exchange Water Conditioners       557         13.4Evaporators       556         13.5Boiler Blowdown       562         13.7Steam Traps       572         13.8Pipeline Separators and Strainers       578         13.9Lubricants and Lubricating Devices       581         Questions and Problems       596		10.7Engine Rating and Efficiency	458
11.1Turbines: General       466         11.2Condensers       497         11.3Spray Ponds and Cooling Towers       504         11.4Condenser Auxiliaries       511         Questions and Problems       515         12. OPERATING AND MAINTAINING TURBINES AND AUXILIARIES       517         12.1Turbines       517         12.2Condensers       536         12.3Cooling, Towers and Spray Ponds       536         12.4Auxiliaries       541         Questions and Problems       545         13. AUXILIARY STEAM-PLANT EQUIPMENT       547         13.1Open Feedwater Heaters       547         13.2Closed Feedwater Heaters       554         13.3Ion-Exchange Water Conditioners       557         13.4Evaporators       560         13.5Boiler Blowdown       562         13.7Steam Traps       573         13.8Pipeline Separators and Strainers       578         13.9Lubricants and Lubricating Devices       581         Questions and Problems       590		Questions and Problems	463
11.2Condensers       497         11.3Spray Ponds and Cooling Towers       504         11.4Condenser Auxiliaries       511         Questions and Problems       515         12. OPERATING AND MAINTAINING TURBINES AND AUXILIARIES       517         12.1Turbines       517         12.2Condensers       536         12.3Cooling, Towers and Spray Ponds       536         12.4Auxiliaries       541         Questions and Problems       545         13. AUXILIARY STEAM-PLANT EQUIPMENT       547         13.1Open Feedwater Heaters       547         13.2Closed Feedwater Heaters       554         13.3Ion-Exchange Water Conditioners       557         13.4Evaporators       556         13.5Boiler Blowdown       562         13.6Piping System       564         13.7Steam Traps       573         13.8Pipeline Separators and Strainers       578         13.9Lubricants and Lubricating Devices       581         Questions and Problems       590	11.	STEAM TURBINES AND AUXILIARIES	466
11.3Spray Ponds and Cooling Towers       504         11.4Condenser Auxiliaries       511         Questions and Problems       515         12. OPERATING AND MAINTAINING TURBINES AND AUXILIARIES       517         12.1Turbines       517         12.2Condensers       530         12.3Cooling, Towers and Spray Ponds       536         12.4Auxiliaries       541         Questions and Problems       545         13. AUXILIARY STEAM-PLANT EQUIPMENT       547         13.1Open Feedwater Heaters       554         13.2Closed Feedwater Heaters       554         13.3Ion-Exchange Water Conditioners       557         13.4Evaporators       556         13.5Boiler Blowdown       560         13.7Steam Traps       573         13.8Pipeline Separators and Strainers       578         13.9Lubricants and Lubricating Devices       581         Questions and Problems       590		11.1Turbines : General	466
11.4Condenser Auxiliaries       511         Questions and Problems       515         12. OPERATING AND MAINTAINING TURBINES AND AUXILIARIES       517         12.1Turbines       517         12.2Condensers       530         12.3Cooling, Towers and Spray Ponds       536         12.4Auxiliaries       541         Questions and Problems       545         13. AUXILIARY STEAM-PLANT EQUIPMENT       547         13.1Open Feedwater Heaters       554         13.2Closed Feedwater Heaters       554         13.3Ion-Exchange Water Conditioners       557         13.4Evaporators       560         13.5Boiler Blowdown       562         13.7Steam Traps       573         13.8Pipeline Separators and Strainers       578         13.9Lubricants and Lubricating Devices       581         Questions and Problems       590		11.2Condensers	497
Questions and Problems       515         12. OPERATING AND MAINTAINING TURBINES AND AUXILIARIES       517         12.1Turbines       517         12.2Condensers       530         12.3Cooling, Towers and Spray Ponds       536         12.4Auxiliaries       541         Questions and Problems       545         13. AUXILIARY STEAM-PLANT EQUIPMENT       547         13.1Open Feedwater Heaters       554         13.2Closed Feedwater Heaters       557         13.4Evaporators       556         13.5Boiler Blowdown       562         13.6Piping System       564         13.7Steam Traps       573         13.8Pipeline Separators and Strainers       578         13.9Lubricants and Lubricating Devices       581         Questions and Problems       590		11.3Spray Ponds and Cooling Towers	504
12. OPERATING AND MAINTAINING TURBINES AND AUXILIARIES       517         12.1Turbines       517         12.2Condensers       530         12.3Cooling, Towers and Spray Ponds       536         12.4Auxiliaries       541         Questions and Problems       545         13. AUXILIARY STEAM-PLANT EQUIPMENT       547         13.1Open Feedwater Heaters       547         13.2Closed Feedwater Heaters       554         13.3Ion-Exchange Water Conditioners       557         13.4Evaporators       560         13.5Boiler Blowdown       562         13.6Piping System       564         13.7Steam Traps       573         13.8Pipeline Separators and Strainers       578         13.9Lubricants and Lubricating Devices       581         Questions and Problems       590		11.4Condenser Auxiliaries	511
12.1 Turbines       517         12.2 Condensers       530         12.3 Cooling, Towers and Spray Ponds       536         12.4 Auxiliaries       541         Questions and Problems       545         13. AUXILIARY STEAM-PLANT EQUIPMENT       547         13.1 Open Feedwater Heaters       547         13.2 Closed Feedwater Heaters       554         13.3 Ion-Exchange Water Conditioners       557         13.4 Evaporators       560         13.5 Boiler Blowdown       562         13.6 Piping System       564         13.7 Steam Traps       573         13.8 Pipeline Separators and Strainers       578         13.9 Lubricants and Lubricating Devices       581         Questions and Problems       590		Questions and Problems	515
12.2Condensers       536         12.3Cooling, Towers and Spray Ponds       536         12.4Auxiliaries       541         Questions and Problems       545         13. AUXILIARY STEAM-PLANT EQUIPMENT       547         13.1Open Feedwater Heaters       547         13.2Closed Feedwater Heaters       554         13.3Ion-Exchange Water Conditioners       557         13.4Evaporators       560         13.5Boiler Blowdown       562         13.6Piping System       564         13.7Steam Traps       573         13.8Pipeline Separators and Strainers       578         13.9Lubricants and Lubricating Devices       581         Questions and Problems       590	12.	OPERATING AND MAINTAINING TURBINES AND AUXILIARIES	517
12.3Cooling, Towers and Spray Ponds       536         12.4Auxiliaries       541         Questions and Problems       545         13. AUXILIARY STEAM-PLANT EQUIPMENT       547         13.1Open Feedwater Heaters       547         13.2Closed Feedwater Heaters       554         13.3Ion-Exchange Water Conditioners       557         13.4Evaporators       560         13.5Boiler Blowdown       562         13.6Piping System       564         13.7Steam Traps       573         13.8Pipeline Separators and Strainers       578         13.9Lubricants and Lubricating Devices       581         Questions and Problems       590		12.1Turbines	517
12.4Auxiliaries       541         Questions and Problems       545         13. AUXILIARY STEAM-PLANT EQUIPMENT       547         13.1Open Feedwater Heaters       547         13.2Closed Feedwater Heaters       554         13.3Ion-Exchange Water Conditioners       557         13.4Evaporators       560         13.5Boiler Blowdown       562         13.6Piping System       564         13.7Steam Traps       573         13.8Pipeline Separators and Strainers       578         13.9Lubricants and Lubricating Devices       581         Questions and Problems       590		12.2Condensers	530
Questions and Problems       545         13. AUXILIARY STEAM-PLANT EQUIPMENT       547         13.1 Open Feedwater Heaters       547         13.2 Closed Feedwater Heaters       554         13.3 Ion-Exchange Water Conditioners       557         13.4 Evaporators       560         13.5 Boiler Blowdown       562         13.6 Piping System       564         13.7 Steam Traps       573         13.8 Pipeline Separators and Strainers       578         13.9 Lubricants and Lubricating Devices       581         Questions and Problems       590		12.3Cooling, Towers and Spray Ponds	536
13. AUXILIARY STEAM-PLANT EQUIPMENT       547         13.1 Open Feedwater Heaters       547         13.2 Closed Feedwater Heaters       554         13.3 Ion-Exchange Water Conditioners       557         13.4 Evaporators       560         13.5 Boiler Blowdown       562         13.6 Piping System       564         13.7 Steam Traps       573         13.8 Pipeline Separators and Strainers       578         13.9 Lubricants and Lubricating Devices       581         Questions and Problems       590			541
13.1 Open Feedwater Heaters54713.2 Closed Feedwater Heaters55413.3 Ion-Exchange Water Conditioners55713.4 Evaporators56013.5 Boiler Blowdown56213.6 Piping System56413.7 Steam Traps57313.8 Pipeline Separators and Strainers57813.9 Lubricants and Lubricating Devices581Questions and Problems590		Questions and Problems	545
13.1 Open Feedwater Heaters54713.2 Closed Feedwater Heaters55413.3 Ion-Exchange Water Conditioners55713.4 Evaporators56013.5 Boiler Blowdown56213.6 Piping System56413.7 Steam Traps57313.8 Pipeline Separators and Strainers57813.9 Lubricants and Lubricating Devices581Questions and Problems590	13.	AUXILIARY STEAM-PLANT EQUIPMENT	547
13.3Ion-Exchange Water Conditioners55713.4Evaporators56013.5Boiler Blowdown56213.6Piping System56413.7Steam Traps57313.8Pipeline Separators and Strainers57813.9Lubricants and Lubricating Devices581Questions and Problems590			547
13.4Evaporators56013.5Boiler Blowdown56213.6Piping System56413.7Steam Traps57313.8Pipeline Separators and Strainers57813.9Lubricants and Lubricating Devices581Questions and Problems590		13.2Closed Feedwater Heaters	554
13.5 Boiler Blowdown56213.6 Piping System56413.7 Steam Traps57313.8 Pipeline Separators and Strainers57813.9 Lubricants and Lubricating Devices581Questions and Problems590		13.3Ion-Exchange Water Conditioners	557
13.6Piping System56413.7Steam Traps57313.8Pipeline Separators and Strainers57813.9Lubricants and Lubricating Devices581Questions and Problems590		13.4Evaporators	560
13.7 Steam Traps 573 13.8 Pipeline Separators and Strainers 578 13.9 Lubricants and Lubricating Devices Questions and Problems 590		13.5Boiler Blowdown	562
13.8Pipeline Separators and Strainers57813.9Lubricants and Lubricating Devices581Questions and Problems590		13.6Piping System	564
13.9 Lubricants and Lubricating Devices  Questions and Problems  581  590			573
Questions and Problems 590		13.8Pipeline Separators and Strainers	578
Questions and Problems 590			581
INDEX 621			590
INDEX		621	